The Nigerian Society of Engineers
Minna Branch
1st NSE Minna Branch National Conference 2021

Conference theme
Role of Engineering in Sustainable Development Goals

SUSTAINABLE DEVELOPMENT IN CONSTRUCTION INDUSTRY USING PALM KERNEL SHELL ASH AS PARTIAL REPLACEMENT FOR CEMENT

S.O. Atuluku[1] and T.E. Adejumo[2]

Civil Engineering Department, Federal University of Technology, Minna, Nigeria
*Corresponding author email: isaiahsurniel@gmail.com +2348137736804

ABSTRACT

The construction sector, in modern times, is faced by multi-faceted challenges primarily due to the increase in the urban population and declining natural resources that facilitates the production of construction materials. The world in general, has turned its focus on environmental effects associated with improper disposal of waste materials which results in excessive accumulation of dirt and pollution. Millions of tons of palm kernel shell are constantly being dumped in the environment through careless disposal and they are mostly resistant to degradability which makes it a problem to the environment. This study presents the sustainable development in construction industry using palm kernel shell ash as partial replacement for cement. All the test procedures were carried out in accordance with British Standard Institution guide. The method adopted in the preparation of concrete was absolute volume method and concrete moulds of 150mm × 150mm × 150mm dimensions were used. The palm kernel shell ash was obtained by burning palm kernel shell at 900^0C, the cement was replaced by palm kernel shell ash at 5, 10 and 15%. The optimum compressive strength of concrete at 28 days curing is 26.53 N/mm^2, which is higher than that of 7, 14 and 21 days. The maximum compressive strength were obtained to be 19.10 N/mm^2, 20.09 N/mm^2, and 22.87 N/mm^2 at 7, 14 and 21 curing respectively. Therefore, the study revealed that the use of agro-waste to develop sustainable construction materials was effective, as the developed materials adhered to established building standards and reduced cost of cement. Therefore, this indicates that palm kernel shell ash has the potential to replace conventional construction materials and hence achieve economic, environmental, and social sustainability in the long run.

Keywords: *Cement; Construction; Palm kernel shell ash; Partial replacement; Sustainable development.*

1 INTRODUCTION

The adoption of new materials in today's construction market is the result of resource constraint, advances in engineering techniques and cost saving measures. There has been so much demand in construction industries on the need for construction materials in many countries around the world. Efforts have equally been made by various researchers to reduce the cost of concrete and hence total construction cost by investigating and ascertaining the usefulness of material which would be classified as agricultural and industrial wastes (Tangchirapat, 2009).

Due to the limited usage of these wastes materials, the rate at which they are disposed as landfill materials are expected to increase consequently leading to potential failure, environmental problems, accumulation, burning and landfill of solid waste disposal which can be expensive and undesirable. When these materials are reused in workable areas such as in the construction industry it is considered as an active area over the entire world which is a current practice (Olowe and Adebayo 2015).

In the early 1960s, Nigeria was the world's largest palm oil producer with global market share of 43%. Today, it is the 5th largest producer with less than 2% of total global market production of 74.08 million MT. In 1966, Malaysia and Indonesia surpassed Nigeria as the world's largest oil producers. Since then, both countries combined produce approximately 80% of total global output, with Indonesia alone responsible for over half i.e. 53.3% of global output. According to the Central Bank of Nigeria (CBN), if Nigeria had maintained its market dominance in the palm oil industry, the country would have been earning approximately $20 billion annually from cultivation and processing of palm oil as at today (PwC Analysis, 2019)

The palm kernel shell (PKS) is a waste material obtained during the extraction of palm oil by crushing the palm nut in the palm oil mills. They are hard, flaky and of irregular shape. These wastes if properly pulverized has cementitious properties hence making it pozzolanic (Awal and Hussin, 2011). The recycling of these waste into value added products in construction applications will reduce demand on non-renewable natural resources which are fast depleting as well as scarce and costly coupled with the energy required in processing them. This also will further enhance local material research, development, production, utilization and improvement which will enhance a long term economy by adequately enhancing a cleaner environment and achieving concrete performances with physical tests (Neville, 2011).

Previous researches on the use of palm kernel shell ash focus more on the strength properties rather than its strength, full adoption and sustainability. The underlying objectives of the study is to investigate the strength properties of the palm kernel shell ash, sustainable principles on effectiveness of palm kernel shell ash as partial replacement for cement and a possible reduction of cost in the construction industry.

2 METHODOLOGY

Materials

The materials (raw) required for these research work includes: Dangote brand of Ordinary Portland cement (OPC), fine aggregate, coarse aggregate, palm kernel shell ash (PKSA) and clean water. The palm kernel shells used in these research were obtained at Umomi in Kogi State. The Ordinary Portland cement and aggregates were obtained at Albashiri quarry site along Bida – Minna road. The palm kernel shell was burnt in an incinerator using a fabricated furnace behind the Civil Engineering Laboratory, after which the ash was sieved using sieve 75µm to obtain a fine powdery form. Tap water free from contaminants was obtained from Civil Engineering Laboratory, Federal University of Technology, Minna, and was used for mixing and also curing of the concrete.

Methods

The production of concrete tests was conducted in Civil Engineering Laboratory, Federal University of Technology, Minna. The materials mentioned in 2.1 above were used, prescribed mix design proportion of 1:2:4 with water cement ratio of 0.6. A total of 48 concrete cubes specimen (150mm X 150mm X 150mm) were cast according to (BS 1881: part 108, 1983), cured according to (BS1881: part 111, 1983) and tested according to (BS 1881: part 116, 1983) at the curing ages of 7, 14, 21, and 28 days respectively.

Tests including sieve analysis according to (BS 812: part 103.1, 1985), specific gravity according to (BS 812: part 107, 1995), bulk density according to (BS 812: part 108, 1995), aggregate impact value test according to (BS 812: part 2, 1995), water absorption test according to (BS 812: part 107, 1995), slump test according to (BS 1881: part 102, 1983) and finally the compressive strength test according to (BS 1881: part 116, 1983) after curing for 7, 14, 21, and 28 days were carried out.

2.1 CASTING AND CURING PROCESS

Casting of concrete cubes

After concrete mixing, slump test precedes casting of concrete cubes. The concrete mould of 150mm × 150mm × 150mm dimensions was used. The moulds were rubbed with black engine oil so as to allow easy removal of the sample. The moulds were placed on a rigid horizontal surface and filled with concrete in such a way as to remove entrapped air as possible and produce full compaction of the concrete with neither segregation nor laitance. The concrete was poured inside the mould in three layers; each layer being given 25 strokes of the 16mm tamping rod. Each layer is of approximately 50mm deep. The test cube was prepared in accordance to (BS 1881: part 108, 1983).

Curing of concrete cube

Curing follows immediately after de-molding of the cubes from the mould. The cubes will be submerged immediately in the curing tank for the required curing age of 7, 14, 21, and 28 days which are the ages to be considered for the purpose of this study. The curing of the cubes was carried out in accordance to (BS 1881: part 111, 1983).

Compressive strength test

Curing is succeeded by crushing of the concrete. Crushing operation was performed on concrete cubes by applying compressive force on them gradually until the cubes starts breaking having attained its supposed maximum strength limit in a compressive strength testing machine. Compressive strength test was carried out on the concrete cubes at curing age 7, 14, 21, and 28 days respectively, in accordance to (BS 116: part 116, 1963).

Figure 1: Specimen undergoing compressive strength test

2.2 FIGURES AND TABLES

TABLE 1: PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATE

S/ No	Sieve sizes (mm)	Weight retained (g)	Cumulative weight retained (g)	Cumulative percentage retained (%)	Cumulative Percentage passing (%)
1	5.00	0.21	0.21	0.042	99.96
2	3.35	8.86	9.07	1.814	98.19
3	2.36	27.75	36.82	7.364	92.64
4	2.00	13.72	50.54	10.108	89.89
5	1.18	62.68	113.22	22.644	77.36
6	0.85	57.75	170.97	34.194	65.81
7	0.60	74.93	245.9	49.180	50.82
8	0.43	93.33	339.23	67.846	32.15
9	0.30	79.08	418.31	83.662	16.34
10	0.15	66.76	485.07	97.014	2.99
11	0.08	12.01	497.08	99.416	0.58
12	0.00	2.92	500.00	100.000	0.00
		Total weight:500g			

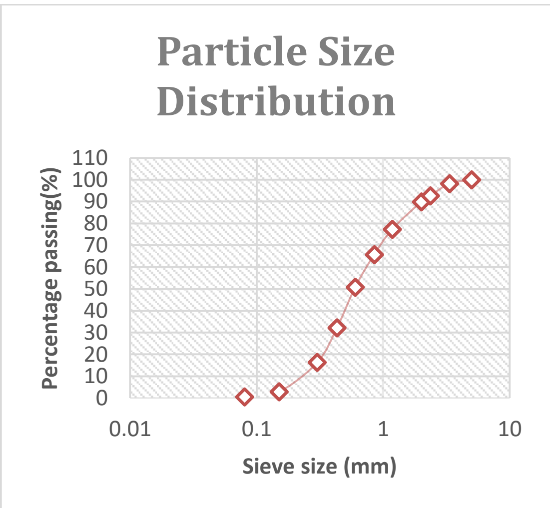

Figure 2: Particle size distribution of fine aggregate

Table 2: SIEVE ANALYSIS OF FINE AGGREGATE

S/No	Sieve sizes (mm)	Weight retained (g)	Cumulative weight retained (g)	Cumulative percentage retained (%)	Cumulative percentage passing (%)
1	20.0	2.50	2.50	50.00	50.00
2	14.0	1.80	4.30	86.00	14.00
3	10.0	0.60	4.90	98.00	2.00
4	6.30	0.10	5.00	100.00	0.00
5	0.00	0.00	5.00	0.00	0.00
			Total weight:5kg		

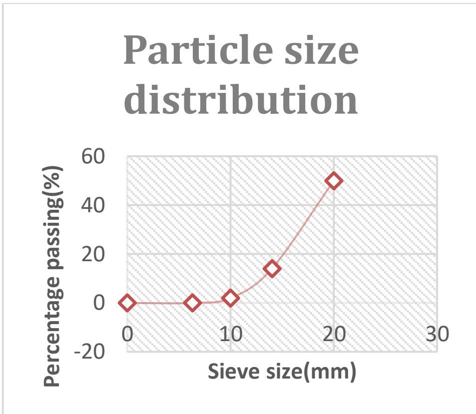

Figure 3: Particle size distribution of coarse aggregate

TABLE 3: SPECIFIC GRAVITY OF PKSA

Trials	1	2	3
Weight of empty vessel	100.8	100.5	100.6
Weight of sample (g)	106	105	105.4
Weight of vessel + sample + water (B)(g)	216.4	214.1	215.2
Weight of vessel + water only (C) (g)	213.2	211.6	212.6
Specific gravity Gs	2.60	2.25	2.18
Average specific gravity		**2.34**	

TABLE 4: COMPRESSIVE STRENGTH AT SEVEN (7) DAYS CRUSHING

Replacement level (%)	Cube number	Mass of cube (kg)	Crushing Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
0%	1	8.9	483.9	21.51	
	2	9.1	379.5	16.86	**19.10**
	3	9.0	425.5	18.91	
5%	1	8.8	398	17.69	
	2	9.1	315	14.00	**16.02**
	3	9.0	368	16.36	
10%	1	8.9	268	11.91	
	2	9.0	297	13.20	**12.21**
	3	8.9	259	11.51	
15%	1	9.0	230	10.22	
	2	8.9	249	11.07	**10.95**
	3	9.1	260	11.56	

TABLE 5: COMPRESSIVE STRENGTH AT TWENTY-EIGHT (14) DAYS CRUSHING

Replacement level (%)	Cube number	Mass of cube (kg)	Crushing Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
0%	1	8.9	454.6	20.20	
	2	8.7	448	19.91	**20.09**
	3	9.0	453.6	20.16	
5%	1	8.8	386	17.16	
	2	9.0	432	19.20	**17.81**
	3	8.9	384	17.07	
10%	1	8.9	285	12.67	
	2	9.0	364	16.18	**14.77**
	3	8.9	348	15.47	
15%	1	9.0	264	11.73	
	2	8.7	240	10.67	**11.69**
	3	9.1	285	12.67	

TABLE 6: COMPRESSIVE STRENGTH AT TWENTY-ONE (21) DAYS CRUSHING

Replacement level (%)	Cube number	Mass of cube (kg)	Crushing Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
0%	1	8.75	563.5	25.04	
	2	8.92	561	18.64	**22.87**
	3	8.86	419.5	24.93	
5%	1	8.60	415	18.44	
	2	8.91	436	19.38	**19.33**
	3	8.73	454	20.18	
10%	1	8.91	329	14.62	
	2	8.79	380	16.89	**15.10**
	3	9.00	310	13.78	
15%	1	9.1	280	12.44	
	2	8.7	281	12.48	**12.29**
	3	9.0	269	11.96	

TABLE 7: CHEMICAL COMPOSITION OF PALM KERNEL SHELL ASH

Chemical composition	**Concentration (%)**
Na_2O	4.928
M_gO	8.529
Al_2O_3	18.991
SiO_2	49.884
P_2O_5	4.561
K_2O	15.049
CaO	3.332
TiO_2	0.668
Fe_2O_3	6.341

TABLE 8: COMPRESSIVE STRENGTH AT TWENTY-EIGHT (28) DAYS CRUSHING

Replacement level (%)	Cube number	Mass of cube (kg)	Crushing Load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
0%	1	8.92	522.5	23.22	
	2	8.78	600	26.67	**26.53**
	3	9.0	667.2	29.65	
5%	1	8.79	455	20.22	
	2	8.81	468	20.80	**20.07**
	3	8.97	432	19.20	
10%	1	8.91	372	16.53	
	2	8.86	385	17.11	**16.25**
	3	8.96	340	15.11	
15%	1	8.93	312	13.87	
	2	9.10	259	11.51	**13.81**
	3	8.86	361	16.04	

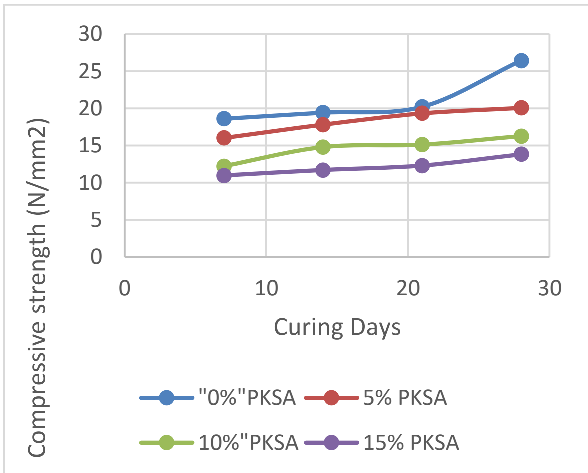

Figure 4: Compressive strength against Curing days of concrete

3 RESULTS AND DISCUSSION

The sieve analysis test was carried out on aggregates and the fineness modulus of fine aggregate was calculated and obtained to be 2.60 which conforms with the requirement that aggregate fineness modulus must fall within the range of 2.3-3.1.The specific gravity for the aggregates were obtained as 2.66 and 2.66 for fine and coarse aggregate respectively which falls within the standard range of specific gravity 2.5 – 3.0. The specific gravity of the palm kernel shell ash was obtained as 2.34 which is lesser compared to that of ordinary Portland cement of 3.15. The bulk densities of the material were found to be 1534.11 kg/m^3 and 1660.82 kg/m^3 for un-compacted and compacted fine aggregates respectively, likewise 1481.48 kg/m^3 and 1656.92 kg/m^3 for un-compacted and compacted coarse aggregates which conforms to the standard range of (1500-1700) kg/m^3 and (1300-1800) kg/m^3 for fine and coarse aggregate respectively. Percentage porosity of fine aggregate and coarse aggregate was found to be 7.63 and 10.59 % respectively, and void ratio 0.42 and 0.44 %.

The water absorption of the aggregate were found to be 24.60 %, 2.8 % and 73.24 % for fine aggregate, coarse aggregate and palm kernel shell ash respectively. The aggregate impact value for the coarse aggregate is 24.40 %.

Table 4, shows the compressive strength of the cubes after 7 days of curing age with 0 % having the highest compressive strength of 19.10 N/mm^2 followed by 5, 10 and 15 % obtained as 16.02 N/mm^2, 12.21 N/mm^2, and 10.95 N/mm^2 respectively.

Table 5, shows the compressive strength for 0, 5, 10 and 15 %, for 14 days curing age and the compressive strength increased than that of 7 days curing ages, the compressive strength obtained are 20.09 N/mm^2, 17.81 N/mm^2, 14.77 N/mm^2 and 11.69 N/mm^2 respectively.

Table 6, shows the compressive strength for 0, 5, 10 and 15 %, for 21 days curing age and the compressive strength increased than that of 7 days curing ages and 14 days curing ages, the compressive strength obtained are 22.87 N/mm^2, 19.33 N/mm^2, 15.10 N/mm^2 and 12.29 N/mm^2 respectively.

Table 7, shows the maximum compressive strength for 0, 5, 10 and 15 %, at 28 days of curing ages with the compressive strength which is higher than that of 7, 14 and 21 days curing ages, the compressive strength obtained are 26.53 N/mm^2, 20.07 N/mm^2, 16 N/mm^2 and 13.81 N/mm^2 respectively. Figure 5 shows the compressive strength against curing age of concrete specimen3

3.1 ECONOMIC ANALYSIS OF PARTIAL REPLACEMENT OF CEMENT BY PALM KERNEL SHELL ASH

The typical cost analysis was conducted for the optimum replacement that met the value of the target strength which is 15% replacement of palm kernel shell ash compared with the control which is 0% palm kernel shell ash. The various materials needed for casting 1m^3 of concrete for both the natural concrete and 15% partially replaced concrete are shown by the following calculations.

From mix design:

Total material used in kg

Cement = 299.69kg per m^3

Water = 179.82kg per m^3

Fine aggregate = 638.34kg per m^3

Coarse aggregate = 1234.72kg per m^3

For Control Experiment

Volume of 1 cube mould:-0.15 × 0.15 × 0.15 = 0.003375m^3

For 12 cubes:-0.003375m^3 × 12 = 0.0405m^3

Add 15% for compaction and wastage

100 + 15 = 115

1.15 × 0.0405m^3 = 0.047m^3

Calculation for the Total Materials

Cement

1m^3 = 299.69kg/m^3

0.047m^3 = X

X = 14.09kg of cement

Sand (fine aggregate)

1m^3 = 638.34kg/m^3

0.047m^3 = X

X = 30.00kg of sand

Gravel (coarse aggregate)

1m^3 = 1234.72kg/m^3

$0.047m^3 = X$

$X = 58.03kg$ of gravel

Water

$1m^3 = 179.82kg/m^3$

$0.047m^3 = X$

$X = 8.45kg$ of water

Total weight of cement needed = 299.69×0.047
= 14.09kg

Total weight of cement replaced by 15% PKSA = $\frac{15}{100} \times 14.09$ = 2.11kg of PKSA

Total weight of cement - 15% PKSA = 14.09 – 2.11
= 11.98kg

Cost of 1 bag of cement 50 kg = N3700

Cost of producing 12 cubes using cement without replacement = $\frac{14.09}{50} \times 3700$ = N1043

Cost of producing 12 cubes using cement with 15% PKSA replacement = $\frac{11.98}{50} \times 3700$ = N887

Cost of saving in cost of cement = 1043 – 887
= N156

Percentage saving in cost of cement = $\frac{156}{1043} \times 100$
= 15%.

4 CONCLUSION

From the results obtained from investigation of sustainable development in construction industry using palm kernel shell ash as partial replacement for cement, the following conclusions were drawn:

1. The sustainability of this development in the construction industry is feasible since over 70% of the states in Nigeria cultivate and harvest oil palm fruit so as to minimize the environmental issues arising from the improper disposal of palm kernel wastes.
2. The total cost required for any construction will be greatly reduced as the use of cement with 15% PKSA replacement will reduce the cost of cement in concrete production to 15% of the total cost.
3. The optimum compressive strength of concrete at 28 days curing age is 26.53 N/mm^2, which is higher than that of 7, 14 and 21 days curing age with their maximum compressive strength of 19.10 N/mm^2, 20.09 N/mm^2, and 22.87 N/mm^2 respectively.
4. Palm kernel shell ash contains all the main constituents of cement although in varying quantities compared to that of ordinary Portland cement. This implies that it will be a good replacement if the right percentage is used.

4.1 RECOMMENDATIONS

From the investigation of effect of partial replacement of cement with palm kernel shell ash on compressive strength of concrete, the following recommendations are made:

1. Reduced cost of construction arising from the use of locally available agricultural waste materials such as palm kernel shell ash will enhance infrastructural developments.
2. Curing of concrete with palm kernel shell ash (PKSA) as partial replacement of cement should reach 28 days in order to obtain maximum compressive strength.
3. Further studies should be carried out on 0 – 50% replacement of cement with palm kernel shell ash in order to reveal its possibility or otherwise.
Palm kernel shell ash (PKSA) can be used as pozzolana in concrete production

ACKNOWLEDGEMENTS

I am totally indebted to my supervisor Engr. Dr. T. E. Adejumo, who did not only take out time to carry me through both in conception and the execution process of this project work, but also created an avenue of bringing out the hidden potentials in me. For all the assistance, fatherly counsels, intellectual contributions, tutoring and constructive criticisms, I say Thank you sir, May God Almighty reward you accordingly. I also wish to acknowledge the contributions of other colleagues who are not included in the authorship of this paper.

REFERENCES

Adama, Y. and Jimoh, Y. A. (2011). Production and classification of Locust Bean Pod Ash as a pozzolana: Project Report, Civil Engineering Portal. Retrieved from http://www.engineeringcivil.com/production-and-classification-of-locust-bean-pod-ash-lbpa-as-a-pozzolana.html 23/02/2020.

American Society for Testing and Materials ASTM C618-92a. (1994) *Chemical and Physical Specifications*, 2 Parks Street, London.

American Society for Testing and Materials ASTM C618, (2005). Specification for coal fly ash and raw or calcined natural pozzolana for use as a mineral admixture in Portland cement concrete. *American Society for Testing and Material*, C618-92a.

Awal, A. S. M. A., and Hussin, M. W. (2011). The Effectiveness of Palm Oil Fuel Ash in preventing expansion due to alkali. *American Journal of Engineering Research*, pp-32-36.

Basel, N. S. and Mohammed, A. R. (2003). Performance of Mortar and Concrete. Construction and Building Materials, 169, pp. 800-818, 2018.

Basri, H. B., Mannan, M. A., and Zain, M. F. M. (1999). Concrete using waste oil palm shell as ash. *Cement and Concrete Research*, 29: 619-622.

BS EN 197:1 (2000). British Standard European Norms 197: Part 1 (2000). Cement-composition, specifications and conformity criteria for common cements. *British Standard Institution*, London.

Basri, H. B., Mannan, M. A., and Zain, M. F. M. (1999). Concrete using waste oil palm shell as ash. *Cement and Concrete Research*, 29: 619-622.

BS 1881 Part 102 (1983). *Method of determination of slump test value of concrete*, British Standard Institute (BSI), 2 Parks Street, London.

BS 1881 Part 103 (1993). *Method of determination of compacting factor test of concrete*, British Standard Institute (BSI), 2 Parks Street, London.

BS 1881 Part 111 (1983). *Method for curing of normal concrete specimens*, British Standard Institute (BSI), 2 Parks Street, London.

BS 1881 Part 114 (1983). *Method for determination of density of hardened concrete cubes*, British Standard Institute (BSI), 2 Parks Street, London.

BS 1881 Part 116 (1983). *Method for determination of compressive strength of concrete cubes*, British Standard Institute (BSI), 2 Parks Street, London.

BS 1881 Part 125 (1983). *Method of sampling fresh concrete in the laboratory*, British Standard Institute (BSI), 2 Parks Street, London.

BS 812 Part 103 (1985). *Method of determination of particle size distribution*, British Standard Institute (BSI), 2 Parks Street, London.

BS 812 Part 103 (1985). *Method of determination of particle size distribution*, British Standard Institute (BSI), 2 Parks Street, London.

BS 812 Part 107 (1995). *Method of determination of specific gravity of aggregates and absorption test*, British Standard Institute (BSI), 2 Parks Street, London.

BS 812 Part 109 (1990). *Method of determination of moisture content of aggregates*, British Standard Institute (BSI), 2 Parks Street, London.

BS 812 Part 2 (1995). *Method of determination of aggregate impact value*, Construction Standard (CS3), North Point, Hong Kong.

BS EN 197:1 (2000). British Standard European Norms 197: Part 1 (2000). Cement-composition, specifications and conformity criteria for common cements. *British Standard Institution*, London.

Camoes, A. and Ferreira, R. M. (2010). Structures and Architecture. University of Mingho, Portugal.

Chen, C., Harbert, G., Bouzidi, Y., Jullien, A. (2010). Environmental impact of production: Details of the different processes and cement plant variability evaluation. *Journal of cleaner production* 18, 478-485

Fadele, O. A. (2016). Compressive strength of concrete containing palm kernel shell ash. *American Journal of Engineering Research.*, Vol-5, issue-12, pp-32-36.

Gworipalan, N., Cabrera, J., Cusens, A. R., and Wainwright, P. J. (1992). Effect of Curing on Durability of Concrete. *ACI Compilation 24. American Concrete Institute*, Farmington Hills, Michgan, USA, pp. 47-54.

https://www.agriculturenigeria.com/manuals/production/crop-production/general-crops/oil-palm/ >

http://www.pwc.com/ng > x-raying the Nigerian palm oil sector.

Jackson, P. J. (1983). Building Materials and construction. Retrieved from https://books.google.com.ng>books 23/02/2020.

Kong, F. H. and Evans, R. H. (1994). Reinforced and Prestressed Concrete, Chapman and Hall, London.

Mamlouk, M. S. and Zaniewski, J. P. (2006). Materials for Civil and Construction Engineers. pp. 8-10.

Mannan, M. A. and Ganapathy, C. (2004). Concrete from an Agricultural waste-oil palm shell (OPS). *Building and Environment*, 39(4), pp. 441-448.

Neville, A. M and Brooks J. J (2011). Concrete Technology, 2nd Edition, Longman.

Neville, A. M. (1996). Properties of Concrete, *ELBS 5th Edition*. Pitman, London.

Neville, A. M., and Brooks, J. J. (2002). Concrete Technology (2nd Indian reprint). *Pearson Education Limited,* Singapore.

Nilson, A. H. (1980). Design of Concrete Structures. Published by McGraw-Hill Inc. pp. 8-9

Olowe, K. O., and Adebayo, V. B. (2015). Investigation of palm kernel ash as partial replacement for high strength concrete. *International Journal of Civil Engineering.*, Vol-2, issue-4, pp-48-50 retrieved from www.internationaljournalssrg.org 22/02/2020.

Palm Kernel Shell p.d.f retrieved from www.indiamart.com/impcat/pks 20/02/2020.

Price, H.W. (1951). Factors influencing concrete strength. *Journal of American Concrete institute.* Vol. 47, pp. 417-32.

Shetty, M. S. (2005). Concrete technology theory and practice. *First Multicolour Illustrative Revised edition.* Indian.

Tangchirapat, W., Jaturapitakkul, C. and Chindaprasirt, P. (2009). Use of palm oil fuel ash as supplementary cementitious materials for producing high strength concrete. *Construction and Building Materials*, 23(7): 2641-2646.

Tay, J. H. (1990). Ash from oil palm waste as concrete material. *Journal of Materials in Civil Engineering*, 2(2): 619-622.

Teo, D. C. L., Mannan, M. A., Kurian, V. J., Ganapathy, C. (2007). Light weight concrete made from oil palm shell: Structural bond and durability properties. *Building and Environ*ment. 42: 2614–2621.